A Comprehensive View of the 13 December 2006 CME: From the Sun to the Outer Heliosphere

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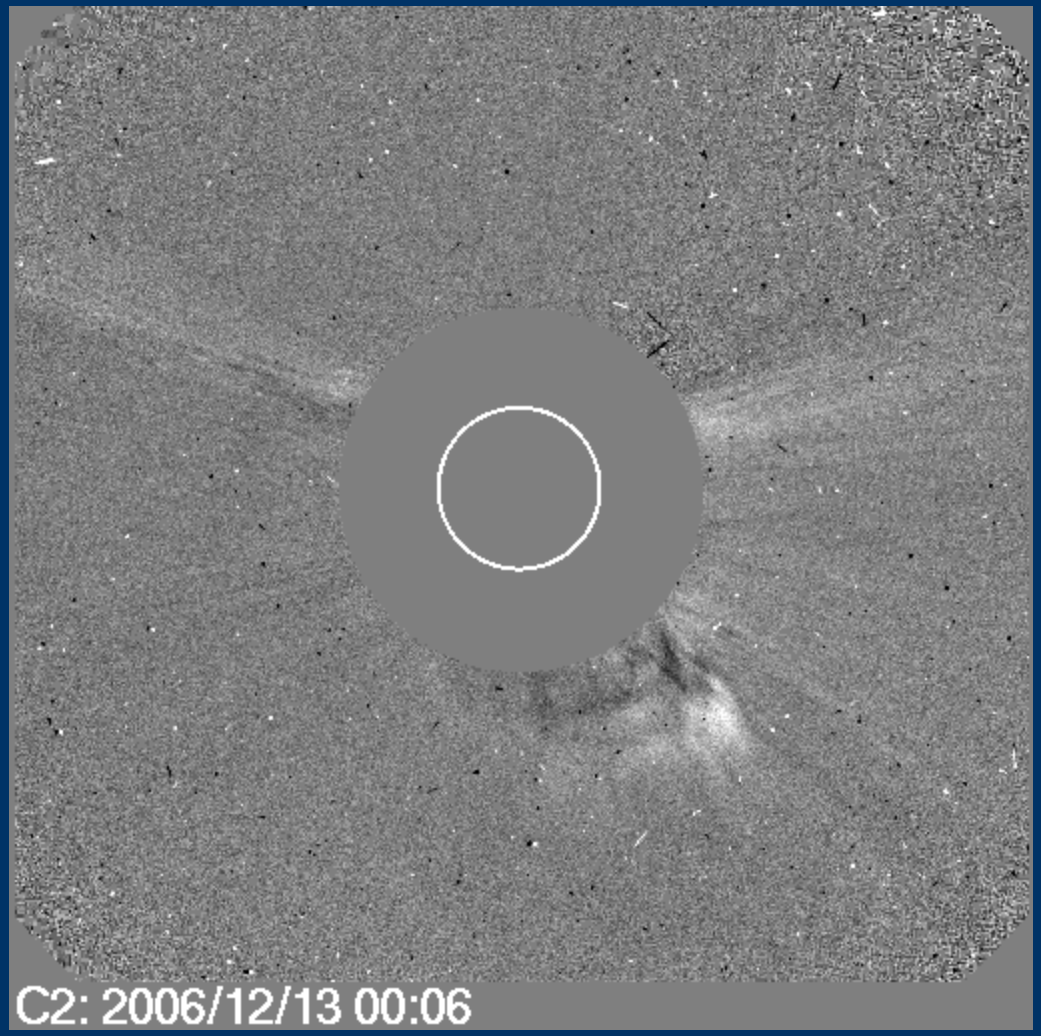
AGU, 12/14/2007

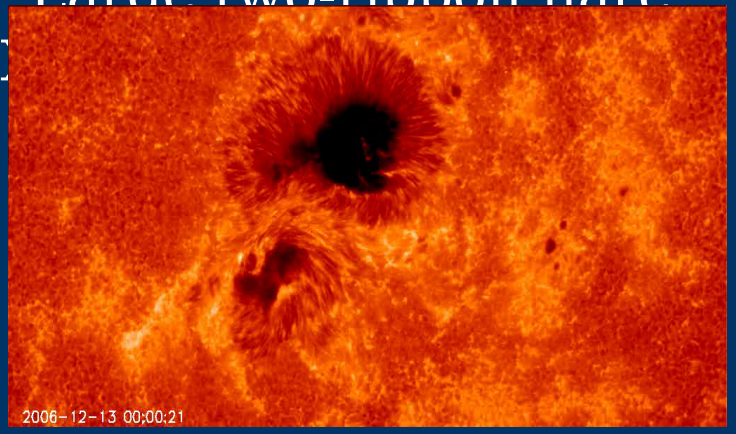
The CME and solar source



LASCO/C2

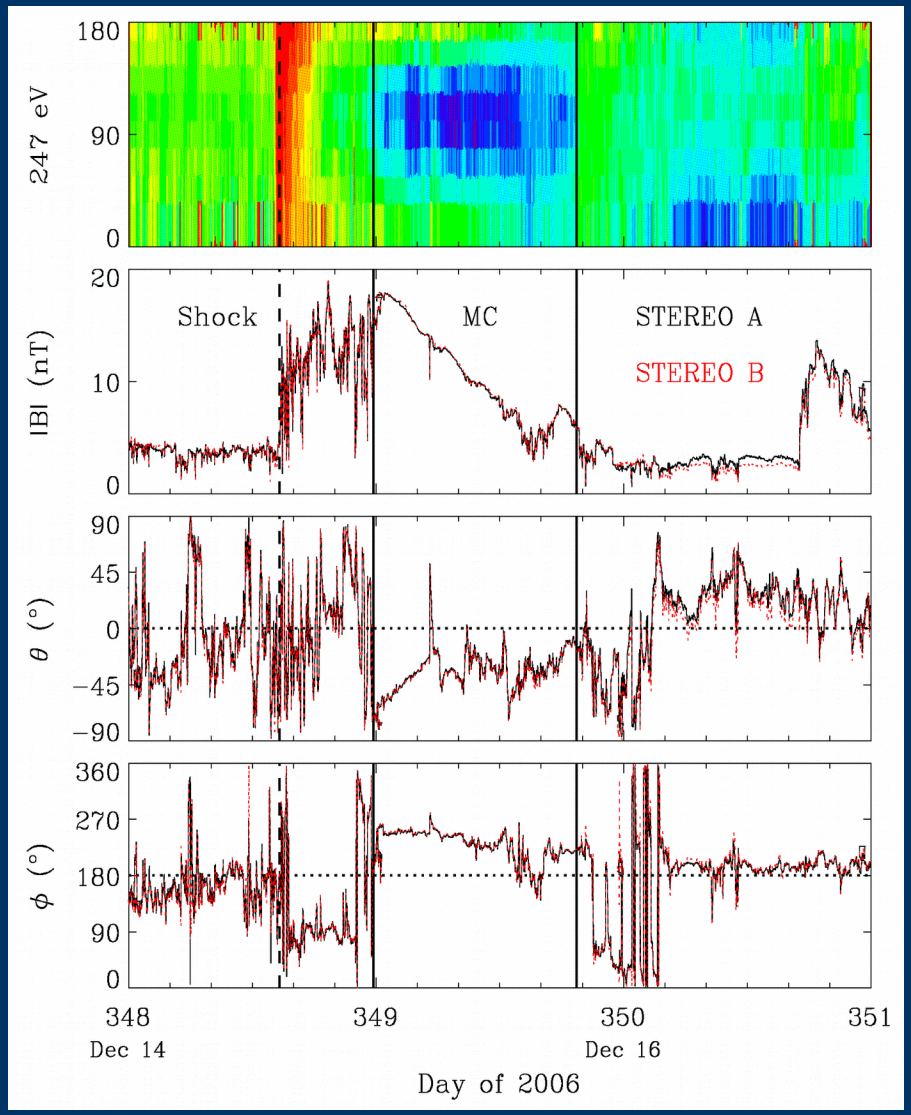
First Biggest halo CME in the STEREO era:

- CME speed, 1770 km/s;
- EIT waves (diffusive EUV brightening across the solar disk);
- Large two-ribbon flare (



Hinode/SOT

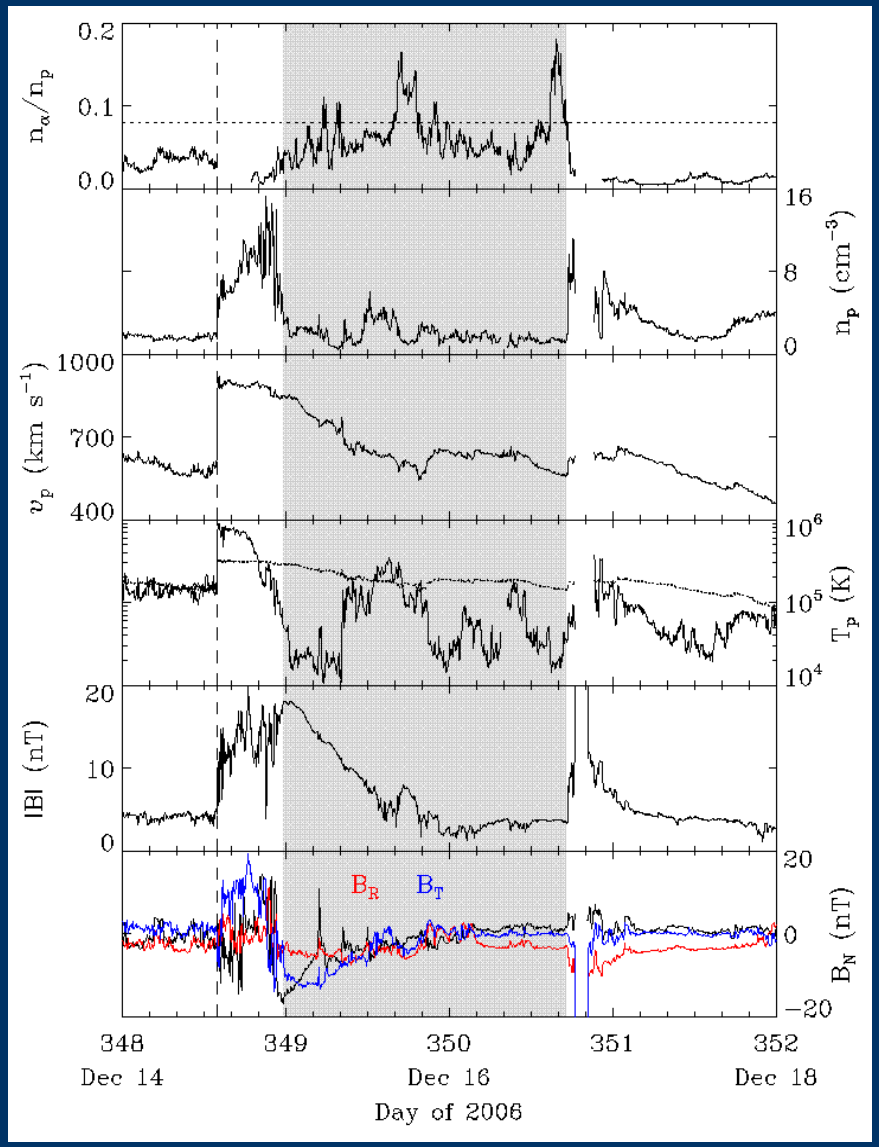
ICME at 1 AU



ICME at STEREO A and B:

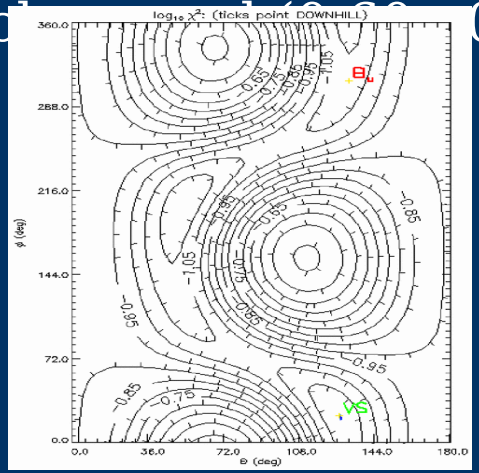
- Preceding shock;
- Bi-directional streaming electrons (BDEs) coincident with strong fields;
- Field stretched behind the ICME;
- A current sheet within the ICME, due to the passage of the comet McNaught?

ICME at 1 AU



ICME at ACE:

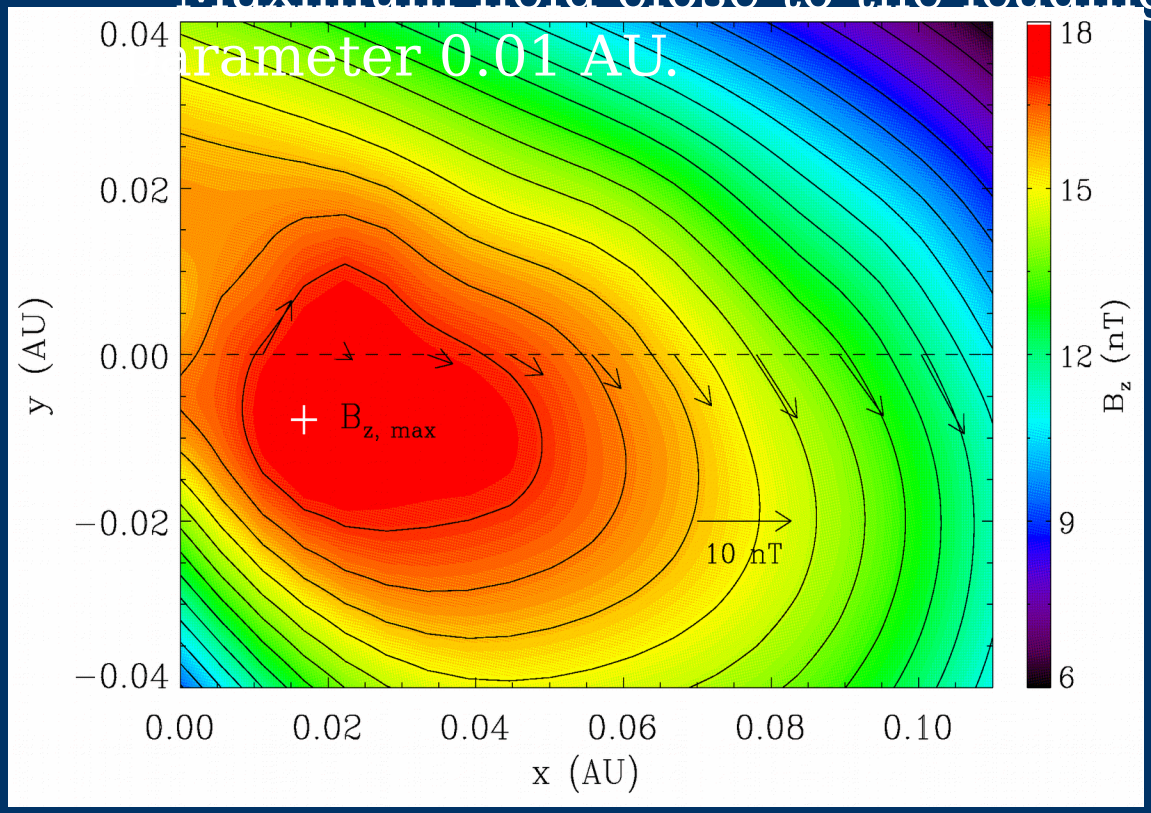
- Larger interval (than indicated by SWEA BDEs) with high helium/proton density ratio and low temperature, width 0.67 AU;
- Shock speed 1030 km/s, smaller than white-light speed (1770 km/s)
- Shock normal ($\theta_{Bn} \approx 56°$. (0.80, 0.77, -0.22)



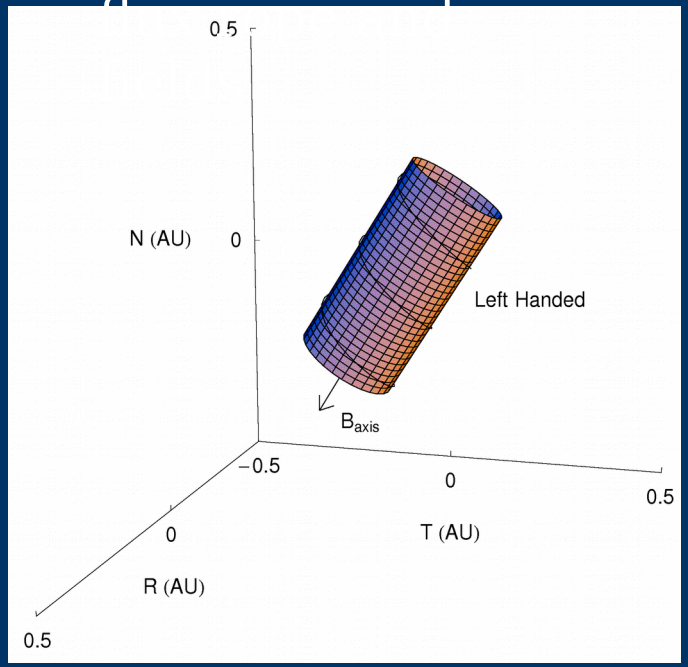
Flux-rope reconstruction (ACE)

Reconstruction using the Grad-Shafranov method, consistent with data: $\theta \approx -57^{\circ}, \varphi \approx 261^{\circ}$,

- Axis orientation in RTN left-handed;
- Maximum field close to the leading edge, and impact parameter 0.01 AU.

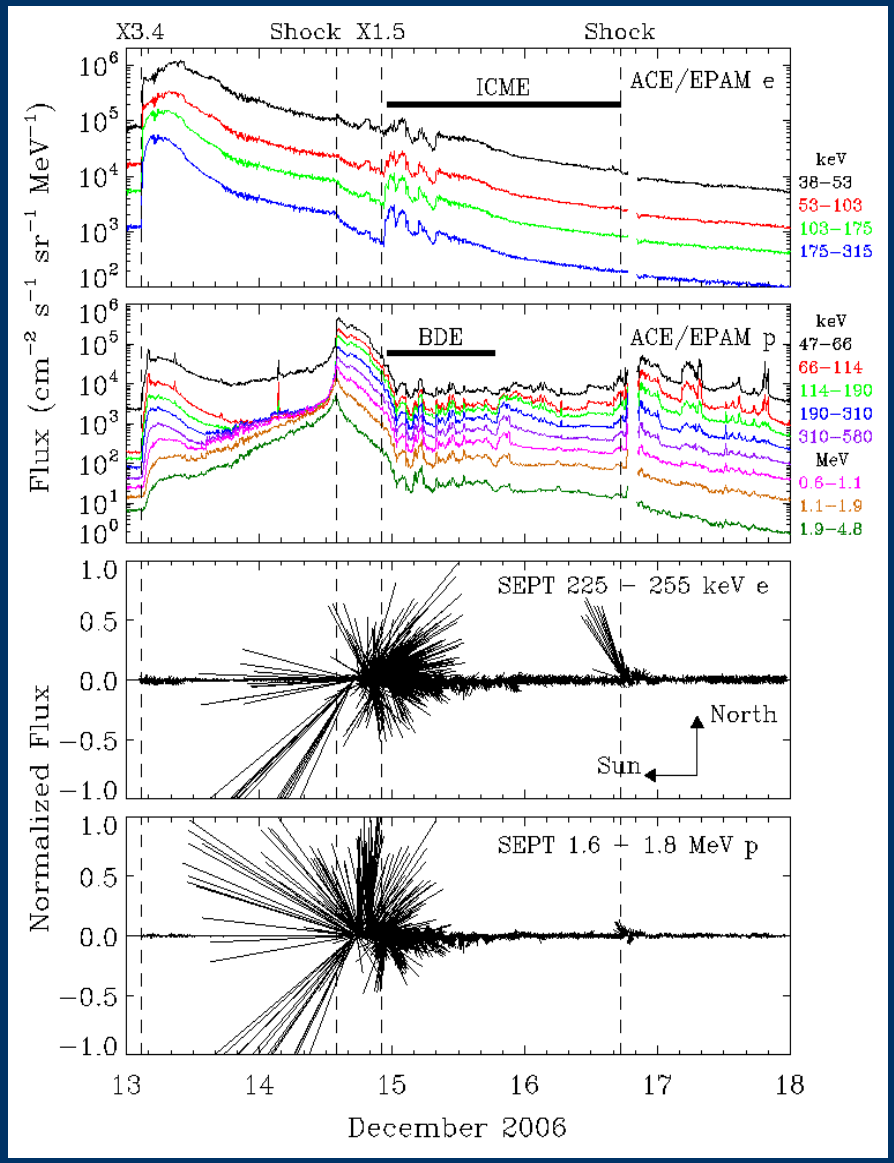


Schematic diagram of the

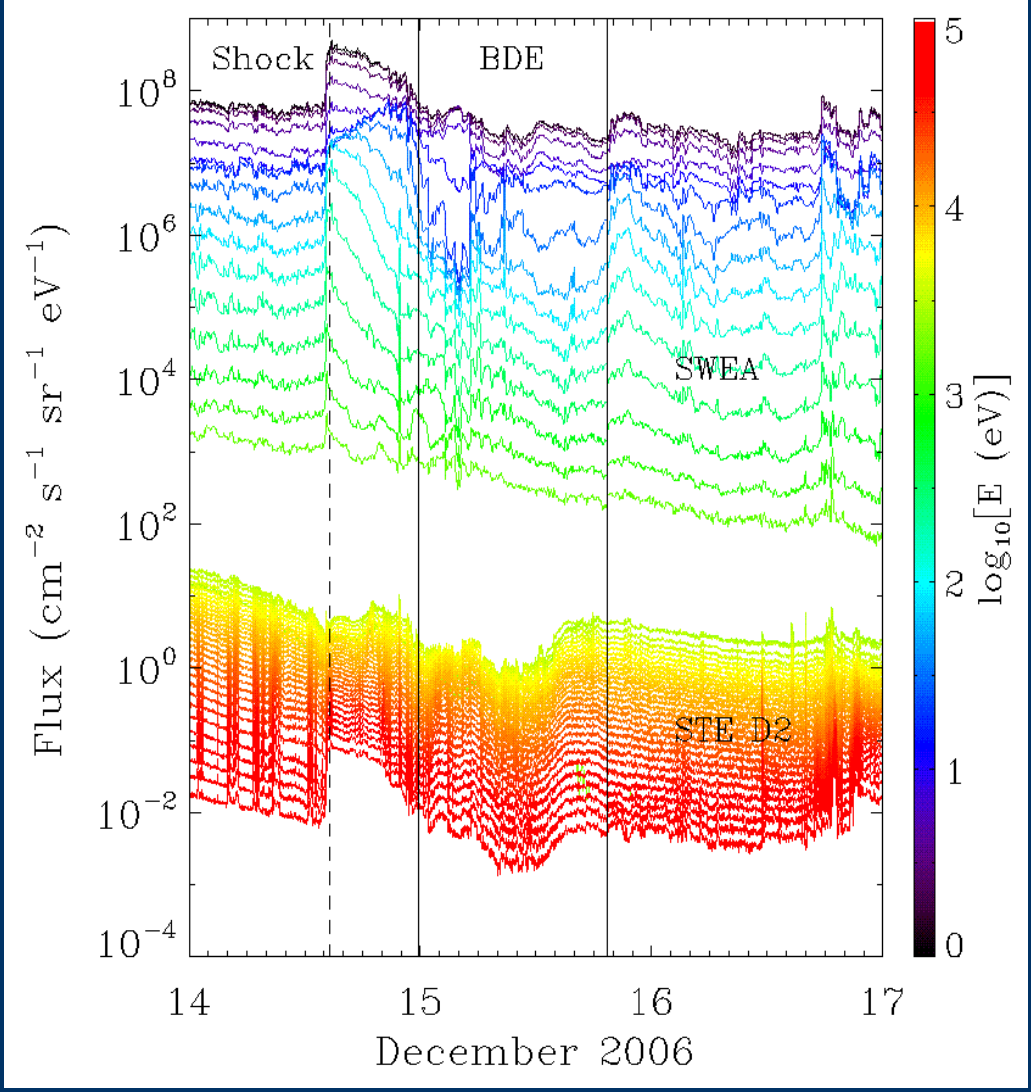


Energetic particle events

- Impulsive SEP event due to the X3.4 flare, but the electrons and ions are more isotropic;
- 1st Shock continues to accelerate MeV ions at 1 AU but has little effect on electrons probably masked by the large preshock electron intensities;
- Energetic electrons within the ICME due to the X1.5 flare indicate the ICME is still magnetically connected to the Sun;
- The X1.5 flare produces particles moving both anti-sunward and sunward (mirror back by the enhanced fields in the ICME/sheath);
- Apparent exclusion of ions from the ICME interior;

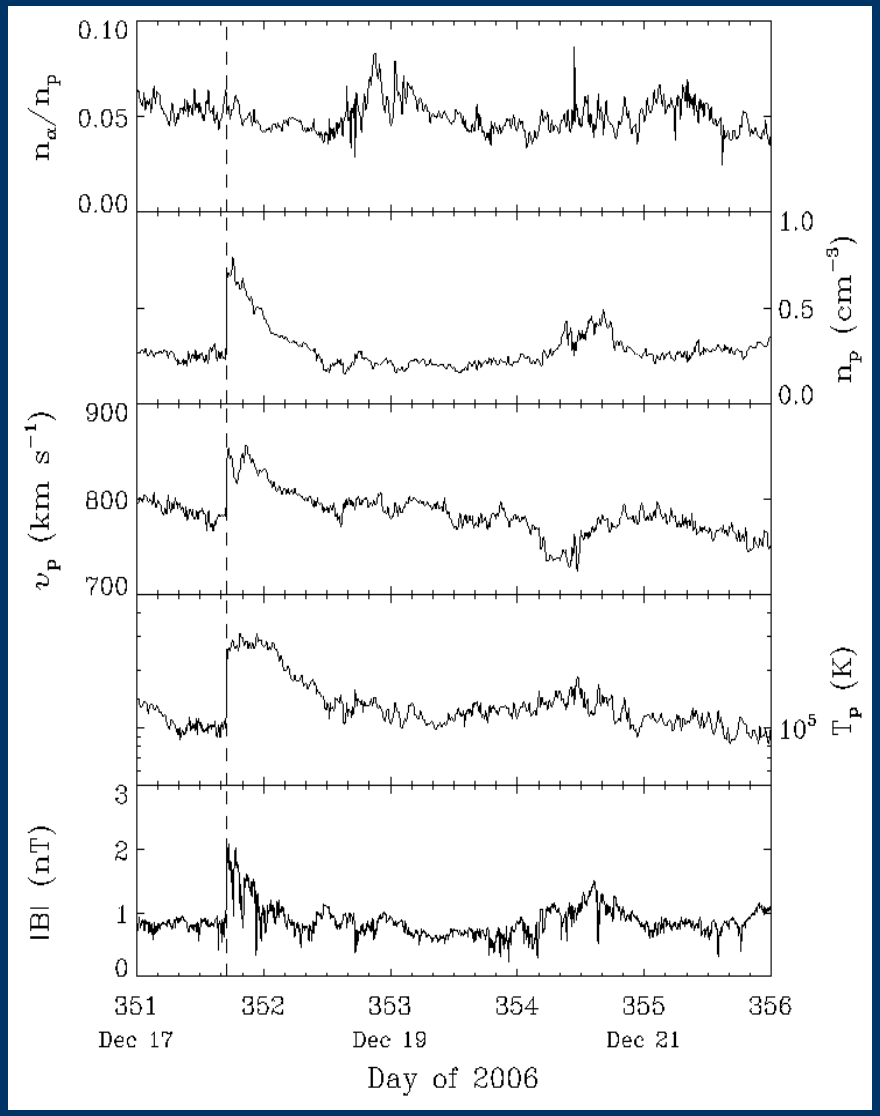


Electron flux across the ICME



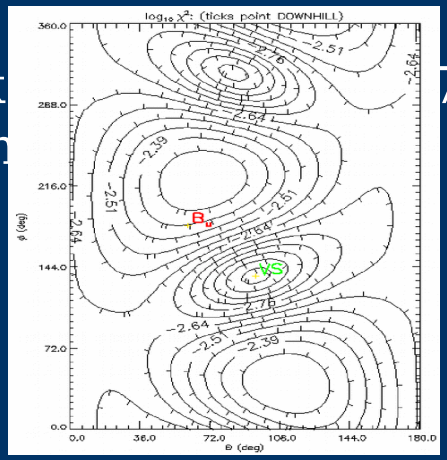
- Clear velocity dispersion at the shock;
- Flux decrease good timing with BDE signature;
- High energy electrons recover earlier (before trailing edge of BDE interval).

ICME at Ulysses



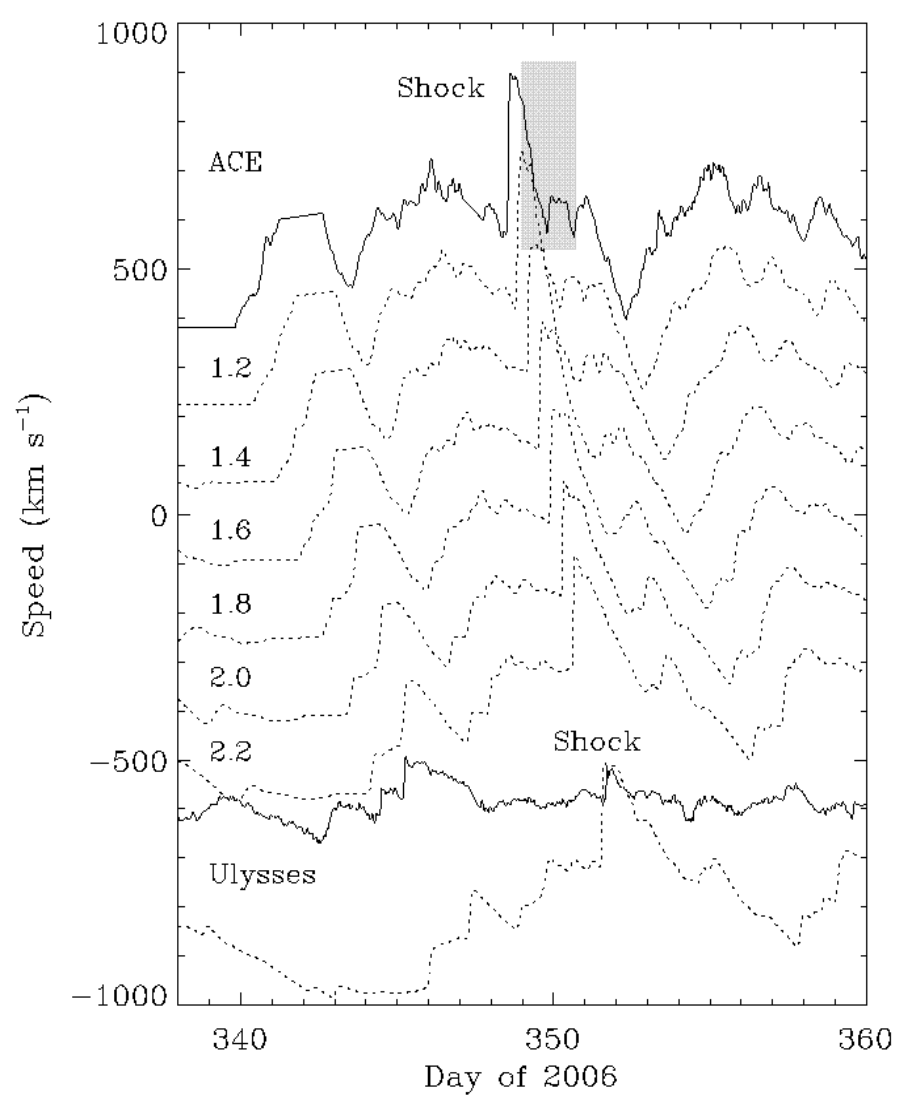
- Ulysses is at 2.73 AU, 117 deg east and 74 deg south of the Earth;
- Latitudinal extent of the shock is large (>74 deg), reasonably surprising;
- No clear ICME signatures;
- Shock speed 870 km/s, smaller t[illegible] 1 AU speed (1030 km/s);
- Shock [illegible] 76, -0.62) in

$\theta_{Bn} \approx 68.$



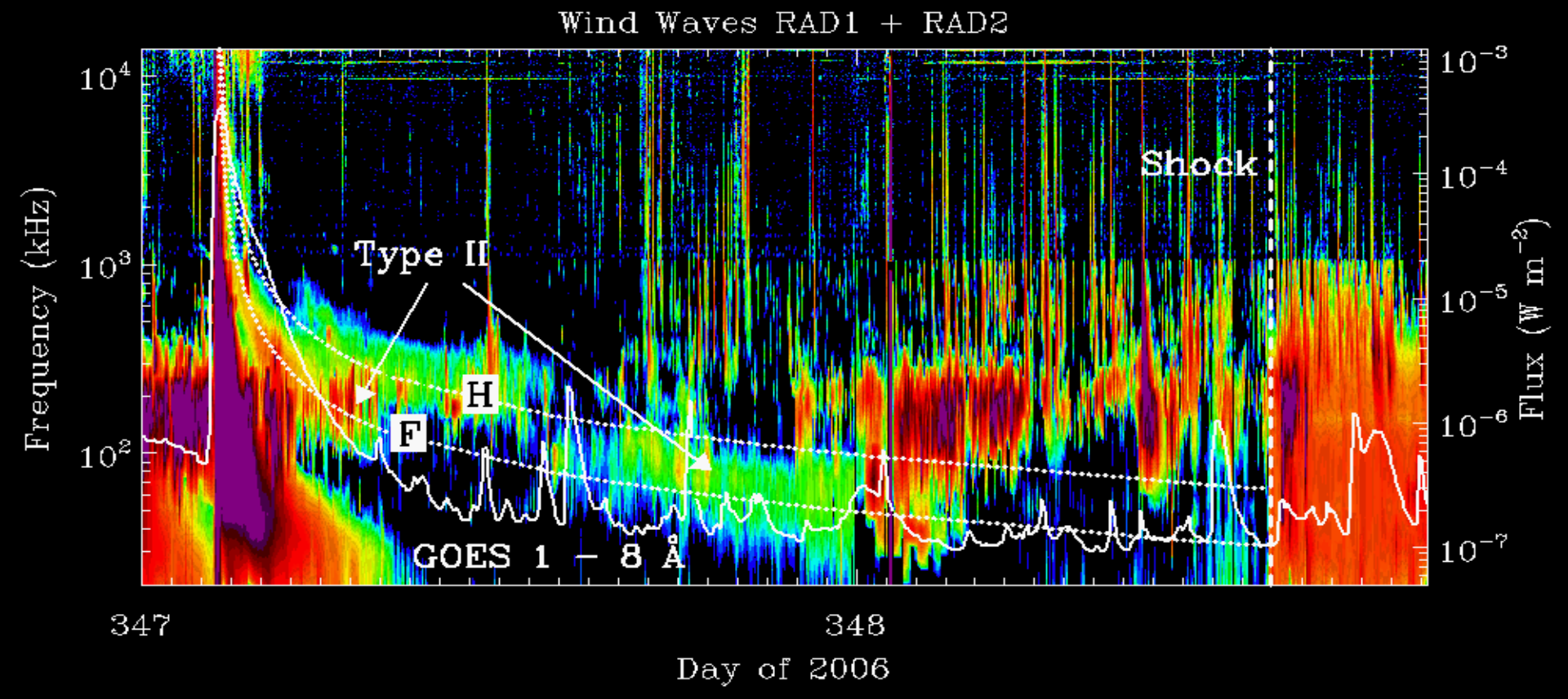
Propagation of the shock

- Use 1 AU data as input to an MHD model;
- Track the shock from MHD model output;
- Good timing of the observed shock with model output at Ulysses.



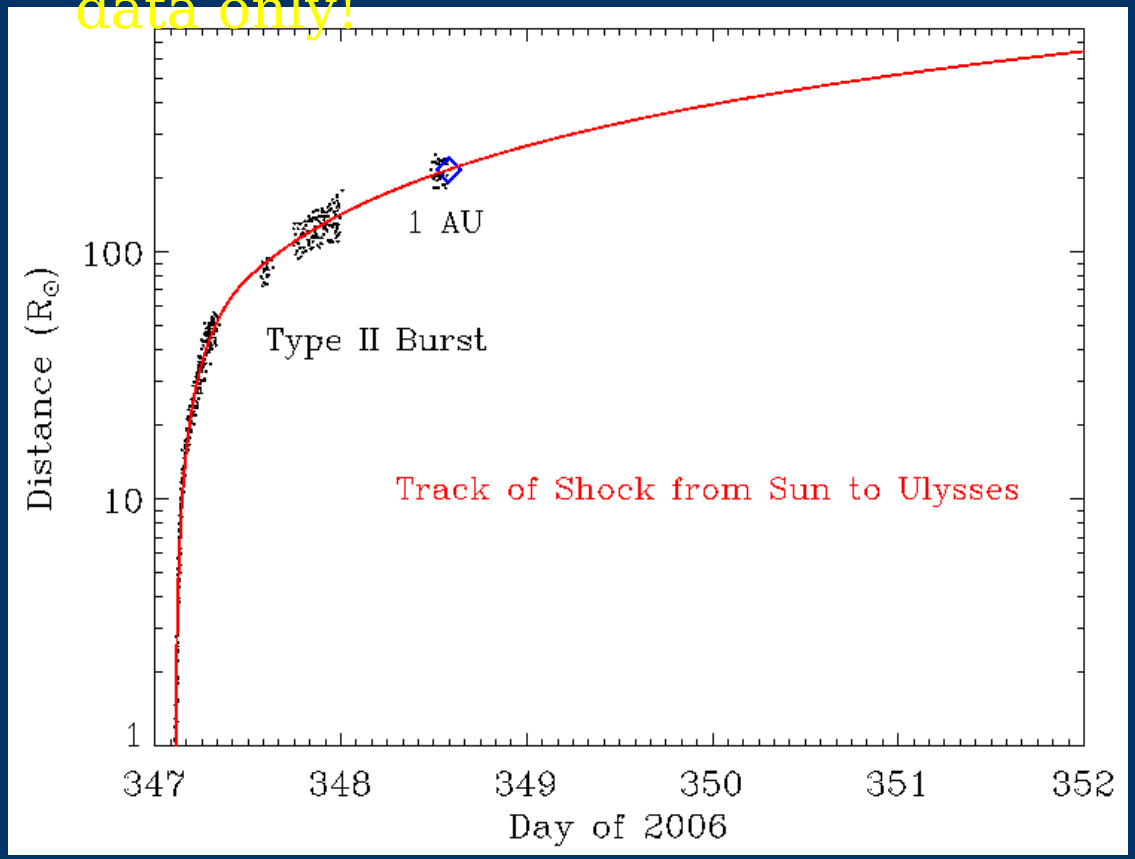
Propagation of the shock

- Good timing of an intense type III burst with the X-ray flux peak, indicating a major flare;
- Track the shock using the frequency drift of $f_p\,(\mathrm{kHz}) \approx 9\sqrt{n(\mathrm{cm}^{-3})}$. bursts,



Propagation of the shock

Fit obtained from radio and 1 AU data only!



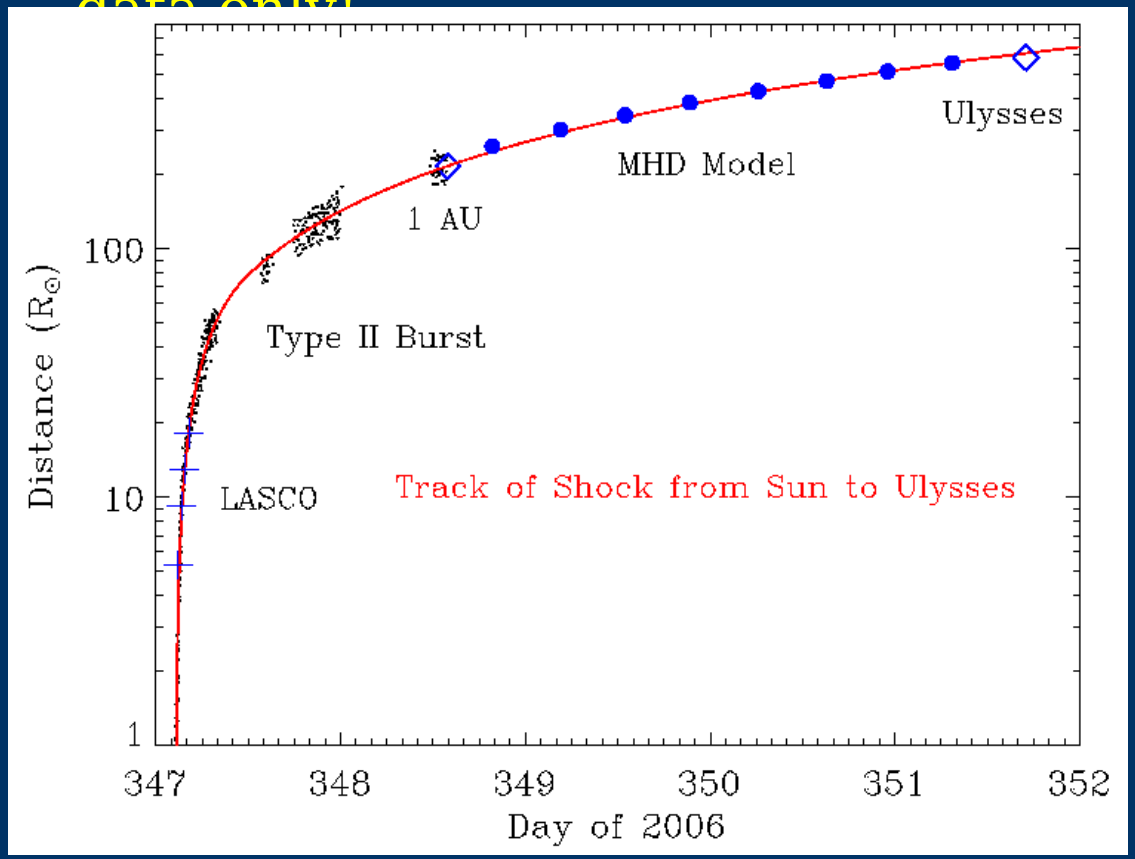
- Assume a density model to convert frequency to distance

$$r(\mathrm{AU}) = \frac{9\sqrt{n_0\,(\mathrm{cm}^3)}}{f_p\,(\mathrm{kHz})};$$

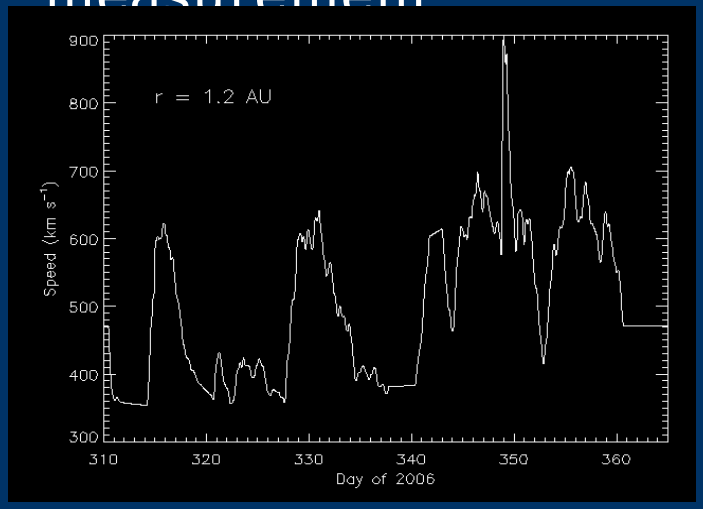
- Use 1 AU data to constrain the height-time profile;
- Speed at the Sun 2200 km/s, larger than projected speed (1770 km/s) ;
- Deceleration within

Propagation of the shock

Fit obtained from radio and 1 AU data only!

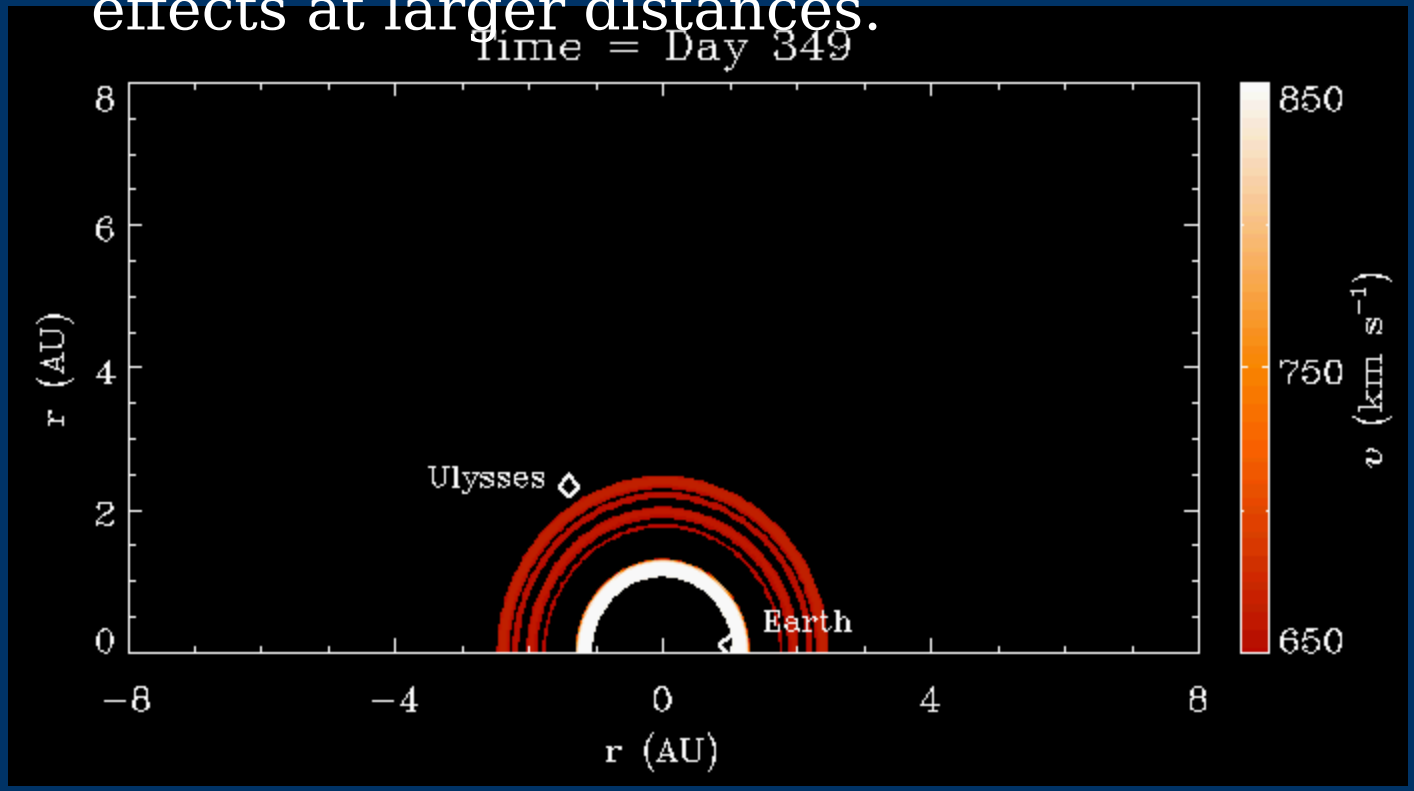


The fit matches white-light data (Lasco CME catalogue), the MHD model output at different distances (below) and Ulysses measurement



Speeds at larger distances

Speed contours from the 1D MHD model. Solar wind speeds quickly weaken beyond 10 AU, so would not produce significant effects at larger distances.



Summary

- A halo CME accompanied by EIT waves and a large solar flare;
- A large ICME embedded with a magnetic cloud (oblique with respect to the filament channel) produces significant space weather effects (D_{st} = -190 nT) and SEP events;
- The preceding shock has a surprisingly large latitudinal extent (>74 deg) and can be tracked amazingly well by white-light, radio, 1 AU and Ulysses in situ data and an MHD model from the Sun all the way to Ulysses.
- Provide benchmark studies for CMEs (and